

DIAGNOSIS OF A UREA SCR CATALYTIC SYSTEM

5 Field of Invention

The present invention relates to a system and a method for diagnosing degradation in a lean exhaust gas aftertreatment system, and more particularly to
10 diagnosing degradation of the NOx sensors coupled upstream and downstream of a NOx catalyst.

Background of the Invention

15 Current emission control regulations necessitate the use of catalysts in the exhaust systems of automotive vehicles in order to convert carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx) produced during engine operation into unregulated
20 exhaust gasses. Vehicles equipped with diesel or other lean burn engines offer the benefit of increased fuel economy, however, catalytic reduction of NOx emissions via conventional means in such systems is difficult due to the high content of oxygen in the exhaust gas.
25 In this regard, Selective Catalytic Reduction (SCR) catalysts, in which NOx is continuously removed through active injection of a reductant, into the exhaust gas mixture entering the catalyst, are known to achieve high NOx conversion efficiency. Typically, reductant, such as
30 aqueous urea, is carried on board of a vehicle, and an injection system is used to supply it into the exhaust gas stream entering the SCR catalyst where it decomposes into hydro cyanic acid (HNCO) and gaseous ammonia (NH₃). The amount of reductant injection is usually determined

based on operating conditions, such as engine speed,
load, catalyst temperature, and on the NOx conversion
efficiency of the catalyst, which can be monitored by
coupling a pair of NOx sensors upstream and downstream of
5 the SCR catalyst.

The inventors herein have recognized that in
order to achieve high NOx conversion efficiency in such
systems, it is important to accurately and quickly
diagnose degradation of the upstream and downstream NOx
10 sensors. The inventors have further recognized that
under some operating conditions, such as when the SCR
catalyst is very cold or very hot, its NOx conversion
efficiency is substantially zero. Therefore, under those
circumstances, the NOx sensor readings upstream and
15 downstream of the catalyst are expected to be
substantially the same.

Summary of the Invention

20 Accordingly, the present invention is directed
to a method for diagnosing degradation of a lean exhaust
gas aftertreatment system, the system including a NOx
catalyst having a first NOx sensor coupled upstream of
the catalyst and a second NOx sensor coupled downstream
25 of the catalyst, the method comprising: comparing a first
NOx sensor measurement and a second NOx sensor
measurement when a catalyst temperature is within a first
predetermined temperature range, and providing an
indication of system degradation when a difference
30 between said first NOx sensor measurement and said second
sensor measurement is greater than a second predetermined
value.

In accordance with one embodiment of the
present invention, the NOx catalyst is a urea-based

Selective Catalytic Reduction (SCR) catalyst. In another embodiment of the present invention, the NOx catalyst is an Active Lean NOx (ALNC) catalyst. In yet another embodiment of the present invention, the NOx catalyst is
5 a Lean NOx Trap (LNT).

In another embodiment of the present invention, an indication of system degradation comprises indicating a first NOx sensor degradation if a difference between said first NOx sensor reading and an estimate of an
10 amount of NOx in an exhaust gas mixture entering the catalyst is greater than a third predetermined value and indicating a second NOx sensor degradation otherwise.

Thus, with such an arrangement, if the catalyst temperature is such that its NOx conversion efficiency is
15 substantially zero, system degradation can be diagnosed if the NOx sensor measurements upstream and downstream of the catalyst are not substantially equal. Additionally, once system degradation is diagnosed, the upstream NOx sensor can be identified as a source of degradation if
20 the difference between an estimated amount of NOx in an exhaust gas mixture entering the catalyst and the first NOx sensor measurement is greater than expected. Otherwise, if the upstream NOx sensor is not degraded, degradation of the downstream NOx sensor is indicated.

25 In yet another aspect of the present invention, method for diagnosing degradation of a NOx sensor coupled downstream of a NOx catalyst, includes: estimating an amount of NOx in an exhaust gas mixture entering the catalyst based on operating conditions; comparing said
30 estimate to a NOx sensor signal when a catalyst temperature is within a predetermined operating range; and providing an indication of the NOx sensor degradation based on a result of said comparison.

Thus, with such an arrangement, downstream NOx sensor degradation can be diagnosed by comparing an estimate of an amount of NOx upstream of the catalyst to the NOx sensor reading downstream of the catalyst when
5 catalyst temperature is such that its NOx conversion efficiency is substantially zero.

An advantage of the above aspect of invention is improved system diagnostics. Yet another advantage of the present invention is improved NOx conversion
10 efficiency.

The above advantages and other advantages, objects and features of the present invention will be readily apparent from the following detailed description of the preferred embodiments when taken in connection
15 with the accompanying drawings.

Brief Description of the Drawings

The objects and advantages described herein
20 will be more fully understood by reading an example of an embodiment in which the invention is used to advantage, referred to herein as the Description of Preferred Embodiment, with reference to the drawings, wherein:

Figures 1A and 1B are schematic diagrams of an
25 engine wherein the invention is used to advantage;

Figure 2 is a an example of one embodiment of an emission control system wherein the present invention is used to advantage; and

Figure 3 is a high level flowchart of an
30 exemplary embodiment of the present invention.

Description of Preferred Embodiment(s)

Internal combustion engine 10, comprising a
5 plurality of cylinders, one cylinder of which is shown in
Figure 1, is controlled by electronic engine controller
12. Engine 10 includes combustion chamber 30 and
cylinder walls 32 with piston 36 positioned therein and
connected to crankshaft 40. Combustion chamber 30 is
10 shown communicating with intake manifold 44 and exhaust
manifold 48 via respective intake valve 52 and exhaust
valve 54. Intake manifold 44 is also shown having fuel
injector 80 coupled thereto for delivering liquid fuel in
proportion to the pulse width of signal FPW from
15 controller 12. Both fuel quantity, controlled by signal
FPW and injection timing are adjustable. Fuel is
delivered to fuel injector 80 by a fuel system (not
shown) including a fuel tank, fuel pump, and fuel rail
(not shown).

20 Controller 12 is shown in Figure 1 as a
conventional microcomputer including: microprocessor unit
102, input/output ports 104, read-only memory 106, random
access memory 108, and a conventional data bus.
Controller 12 is shown receiving various signals from
25 sensors coupled to engine 10, in addition to those
signals previously discussed, including: engine coolant
temperature (ECT) from temperature sensor 112 coupled to
cooling sleeve 114; a measurement of manifold pressure
(MAP) from pressure sensor 116 coupled to intake manifold
30 44; a measurement (AT) of manifold temperature from
temperature sensor 117; an engine speed signal (RPM) from
engine speed sensor 118 coupled to crankshaft 40.

An emission control system 20 is coupled to an exhaust manifold 48 and is described with particular reference to Figure 2.

Referring now to Figure 1B, an alternative
5 embodiment is shown where engine 10 is a direct injection engine with injector 80 located to inject fuel directly into cylinder 30.

Referring now to Figure 2, the emission control system 20 comprises a NOx catalyst 14, which in this
10 embodiment is a urea-based Selective Catalytic Reduction (SCR) catalyst, capable of reducing NOx in an oxygen rich environment. Reductant, such as aqueous urea, is stored in a storage vessel (not shown) and delivered via a reductant injector 16 coupled to exhaust manifold 48
15 upstream of SCR catalyst 14. The reductant is metered out by a pump through a control valve (not shown) where both the pump and the valve are controlled by controller 12. Alternatively, any other means known to those skilled in the art to supply reductant to an exhaust gas
20 aftertreatment device may be used. In an alternative embodiment, catalyst 14 may be an Active Lean NOx (ALNC) catalyst, and the reductant may be hydrocarbon. Two NOx sensors, NO_{x1} (17) upstream and NO_{x2} (18) downstream of the SCR are coupled in the path of the exhaust gas
25 entering and exiting the SCR catalyst. The outputs of these sensors are read by controller 12 and may be used to estimate the NOx conversion efficiency of the SCR. Alternatively, NO_{x1} sensor 17 can be eliminated and the amount of NOx in the exhaust gas mixture entering the SCR
30 catalyst can be estimated based on engine speed, load, exhaust gas temperature or any other parameter known to those skilled in the art to affect engine NOx production.

Controller 12 also calculates the operating temperature of the SCR based on signals from temperature

sensors coupled upstream, T_{in} , and downstream, T_{out} , of the catalyst (not shown). Alternatively, catalyst temperature may be determined by placing a temperature sensor mid-bed of the catalyst, or by any other means
5 known to those skilled in the art to determine SCR catalyst temperature.

Oxidation catalyst 13 is coupled upstream of the SCR catalyst and may be a precious metal catalyst, preferably one containing platinum. The oxidation
10 catalyst exothermically combusts hydrocarbons (HC) in the incoming exhaust gas from the engine thus supplying heat to rapidly warm up the SCR catalyst 14.

Referring now to Figure 3, an exemplary routine for diagnosing degradation of an emission control system
15 in accordance with the present invention is presented. As will be appreciated by one of ordinary skill in the art, the routine may represent one or more of any number of processing strategies such as event-driven, interrupt-driven, multi-tasking, multi-threading, and the like. As
20 such, various steps or functions illustrated may be performed in the sequence illustrated, in parallel, or in some cases omitted. Likewise, the order of processing is not necessarily required to achieve the objects, features and advantages of the invention, but is provided for ease
25 of illustration and description. Although not explicitly illustrated, one of ordinary skill in the art will recognize that one or more of the illustrated steps or functions may be repeatedly performed depending on the particular strategy being used.

30 Proceeding now with Figure 3, first, in step 100, a determination is made whether a predetermined amount of time has elapsed since engine start. This condition is placed to ensure that the NOx sensors upstream and downstream have had a sufficient time to

warm up and become fully operational. If the answer to step 100 is NO, the routine exits. If the answer to step 100 is YES, indicating that NOx sensors are operational, the routine proceeds to step 200 wherein catalyst
5 temperature is determined as a function of temperature measurements upstream and downstream of the catalyst:

$$T_{cat} = f(T_{in}, T_{out})$$

Next, in step 300, a determination is made whether catalyst temperature is lower than T_{low} (e.g.
10 below 150°C for an SCR catalyst) or higher than T_{high} , (e.g., above 450°C for an SCR catalyst) which are temperature ranges wherein NOx conversion efficiency of the catalyst is substantially zero. In other words, NOx conversion efficiency of a catalyst is substantially zero
15 when its temperature is below a predetermined low threshold (such as during cold start) or above a predetermined high threshold (for example, following regeneration). Further, when the catalyst temperature is above T_{high} , all of the ammonia stored on the catalyst has
20 been boiled off and therefore, catalyst NOx conversion efficiency is not affected by its release. If the answer to step 300 is NO, diagnostic conditions are not met, and the routine exits. If the answer to step 300 is YES, indicating that the catalyst temperature is within a
25 range where its NOx conversion efficiency is substantially zero, the diagnostic routine proceeds to step 400 wherein NOx_{in_est} , an estimate of an amount of NOx in the exhaust gas entering the catalyst is determined based on engine speed, load, exhaust gas temperature or
30 any other parameter known to those skilled in the art to affect engine NOx production. The routine then proceeds to step 500 wherein a determination is made whether the difference between the NOx_1 sensor measurement, NOx_{in_meas} ,

and the estimate, NOx_{in_est} , is less than a small predetermined value C_1 . If the answer to step 500 is NO, indicating there is a significant discrepancy between the measured and estimated values of the upstream NOx, the routine proceeds to step 600 wherein a diagnostic code indicating degradation of the upstream NOx_1 sensor is set. The routine then proceeds to step 700 wherein a determination is made whether the difference between NOx_{in_est} and the NOx_2 sensor measurement, NOx_{out_meas} , is less than a small predetermined value C_2 . If the answer to step 700 is YES, indicating that the downstream NOx sensor is not degraded, the routine exits. If the answer to step 700 is NO, the routine proceeds to step 900 wherein a diagnostic code indicating degradation of the NOx_2 sensor is set. The routine then exits.

If the answer to step 500 is YES, indicating that the upstream NOx sensor is not degraded, the routine proceeds to step 800 wherein a determination is made whether the difference between the NOx_1 sensor measurement and the NOx_2 sensor measurement is less than a small predetermined value C_3 . If the answer to step 800 is YES, indicating that the two measurements are within a small, predetermined threshold of each other, the routine exits. If the answer to step 800 is NO, indicating that the downstream NOx sensor performance is degraded, the routine proceeds to step 900.

Therefore, according to the present invention, it is possible to diagnose degradation of the upstream NOx sensor by comparing its signal with an estimate of an amount of NOx upstream of the catalyst. This portion of the diagnostic routine can be performed at any catalyst temperature as long as the sensors themselves are sufficiently heated up to become operational.

Further, once a determination is made that the upstream NOx sensor is functioning, degradation in the downstream NOx sensor can be diagnosed by comparing the signals from the upstream and the downstream NOx sensors, 5 when the catalyst temperature is such that its NOx conversion efficiency is substantially zero. If the difference between the two measurements is greater than a small, predetermined value, the downstream NOx sensor degradation is indicated.

10 In an alternative embodiment (not shown), the upstream NOx sensor may be eliminated, and an estimate of an amount of NOx in an exhaust gas mixture entering the catalyst may be obtained based on engine operating conditions. With such an embodiment, degradation of the 15 downstream NOx sensor may be detected by comparing the estimate to the downstream NOx sensor measurement when the temperature of the catalyst is such that its NOx conversion efficiency is substantially zero. This method can also be used when the upstream NOx sensor is present, 20 but has been diagnosed as degraded.

In yet another alternative embodiment (not shown), the NOx catalyst may be a lean NOx trap (LNT) and the temperature range wherein the diagnostic routine takes place is an LNT temperature at which substantially 25 no NOx conversion or adsorption takes place (e.g. at temperatures above 450°C).

This concludes the description of the invention. The reading of it by those skilled in the art would bring to mind many alterations and modifications 30 without departing from the spirit and the scope of the invention. Accordingly, it is intended that the scope of the invention be defined by the following claims: